BigBOSS
A Stage IV Dark Energy Survey

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for the BigBOSS collaboration.

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The BigBOSS Collaboration

- **CPPM (France)**: Anne Ealet
- **LAM (France)**: Jean-Paul Kneib, Eric Prieto
- **LBNL**: Chris Bebek, Shirley Ho, Michael Lampton, Michael Levi, Nick Mostek, Natalie Roe, Saul Perlmutter, David Schegel, Uros Seljak, Anze Slosar, George Smoot, Martin White
- **NOAO**: Arjun Dey
- **NYU**: Michael Blanton
- **SHAO (China)**: Yipeng Jing
- **Univ. Utah**: Adam Bolton, Kyle Dawson, David Kieda
- **USTC (China)**: Tinggui Wang, Chao Zhai
- **Yale Univ.**: Charlie Baltay, Nikhil Padmanabhan

Collaboration is rapidly evolving!

Outline

BigBOSS - Executive Summary - I

BigBOSS is :

- A Stage IV dark energy experiment to z=3.5
  - Measures the expansion of the Universe
  - Measures the growth of structure in the Universe
  - Complements/Enhances DE science from imaging surveys
- Precision cosmological probe eg.
  - Neutrino masses
  - Inflation
  - Primordial non-gaussianities
- A wide-field multi-object spectrograph
  - Addresses imbalance between imaging and spectroscopic surveys
  - Unique instrument within US astronomical community

BigBOSS - Executive Summary - II

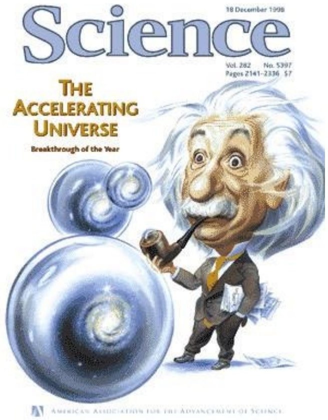
The Survey : Map the LSS to z=3.5

- Galaxies to $z = 2$
  - Luminous Red Galaxies, Emission line galaxies
  - $\bar{n} \sim 4 \times 10^{-4} (h/\mathrm{Mpc})^3$
  - 50M galaxies (12M LRGs, 38M ELGs)
- Quasars from $z = 1.8$ to $z = 3.5$
  - Neutral H absorption
  - 1M QSOs
- $\sim$ Two orders of magnitude more objects than Stage III surveys
- 24K deg^2 (14K North, 10K South)
- 5000 fiber spectrograph on
  - KPNO Mayall 4m (North)
  - CTIO Blanco 4m (South)
- 6 (North) + 4 years (South)

Outline

Motivation - Dark Energy

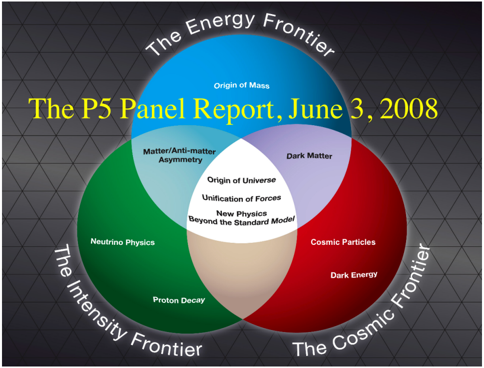
- Evidence for a new energy component (75%) now exists from multiple sources.
- “the nature of dark energy ranks among the very most compelling of all outstanding problems in physical science.” - Dark Energy Task Force
- Dark energy or modified gravity?



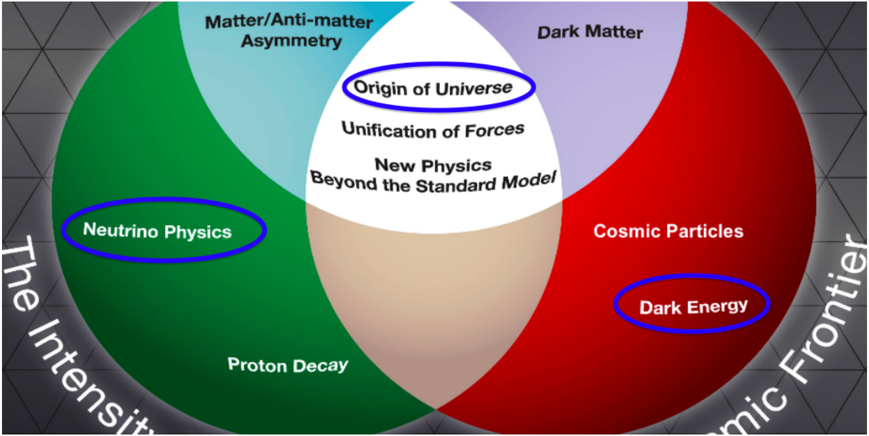
BigBOSS is important to HEP

From P5 :

- "*What is the nature of the dark energy that makes up almost three quarters of the Universe?*"
- "*How did the Universe form?*"
- "*What are the masses . . . of neutrinos and what role did they play in the evolution of the Universe?*"
- ". . . recommends support . . . of dark energy experiments as an **integral** part of the US particle physics program"

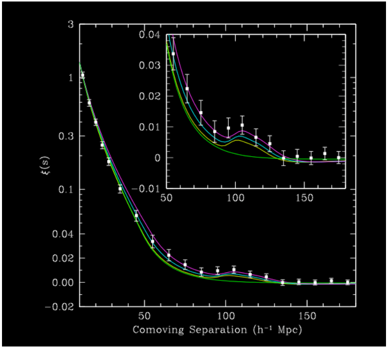


BigBOSS is important to HEP



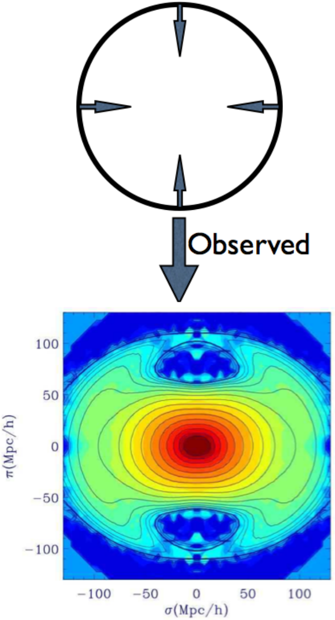
BAO - A Standard Ruler

- Geometrical probe - standard ruler
- Sound waves in the early Universe imprint a feature in the galaxy correlation function
- Measures d_A and $H(z)$
- Calibrated by the CMB
- Robust to astrophysical systematics
- Method demonstrated by SDSS and 2dF redshift surveys



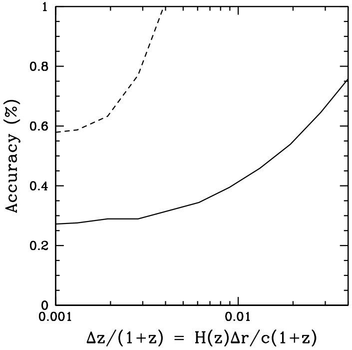
Probing growth

- Redshift space distortions probe growth of structure independently of weak lensing
  - Velocity field sensitive to matter distribution.
  - Velocity field distorts the galaxy correlation function; makes it anisotropic – redshift space distortions.



Spectroscopy is Required

- Photo-z's smear out positions (and the BAO feature) along the LOS.
- Lose all $H(z)$ information; degrade D_A as well.
- Spec. FoM $\sim 5x$ Photo. FoM
- Erase all redshift space distortion information
- Reduce number of modes sampled, larger errors on $P(k)$.
- **Good news:** Astrophysical floor on redshift accuracy of $\sim$ 10 Mpc.
- Do not require very precise redshifts. Previous redshift surveys *significantly* above spec.



Comparing Surveys

	BOSS (Stage III)	**BigBOSS-North (Stage IV)**	**JDEM BAO (Stage IV)**	**BigBOSS-N+S (Stage IV)**
Redshift range	**0<z<0.7**	**0<z<3.5**	**0.7<z<2.0**	**0<z<3.5**
Sky Coverage	10000 $\deg^2$	14000 $\deg^2$	20000 $\deg^2$	24000 $\deg^2$
Wavelength Range	360-1000 nm	340-1130 nm	1100–2000 nm	340nm–1130 nm
Spectral Resolution	1600-2600	2300-6100	200	2300-6100
DETF FoM	57	175	250	286
DETF FoM w/Stage III	**107**	**240**	**313**	**338**

FoM **doubles** when redshift-space distortions are included.

See note on FoM for more details

Cosmological constraints

Multiple points of contact w/ HEP

Significant improvements in cosmological parameters

Sum of neutrino masses	0.019 eV
Number of relativistic species	0.12
Curvature	0.0006
Spectral Index/ Running	0.0030/0.0018

Order of magnitude improvement over Planck

Advantages of BigBOSS

Compared to JDEM BAO :

- Ground-based, lower risk
- Flexible instrumentation; can change targeting depending on science case
- Targeting :
  - Broader redshift range
  - Can do LRGs; allows for systematics tests and cross-correlations with ELGs
  - Hα (JDEM) fluxes uncertain; O[II] (BB) fluxes calibrated by eg. DEEP2 to $z \sim 1.5$.
- Measurements :
  - Single Hα line vs O[II] doublet; possibilities for confusion
  - Grism (JDEM) vs well isolated spectral traces (BB)
  - Higher resolutions implies more ancillary science

Advantages of BigBOSS

Compared to WFMOS :

- WFMOS/Gemini cancelled
- WFMOS/Subaru possible, uncertain US participation
- Not optimized for BAO
  - 1.2 deg^2 field
  - $\leq$ 3000 fibers
  - $<$ 60 nights
- No wide field US spectroscopic facility to complement imaging facilities (exists/planned)

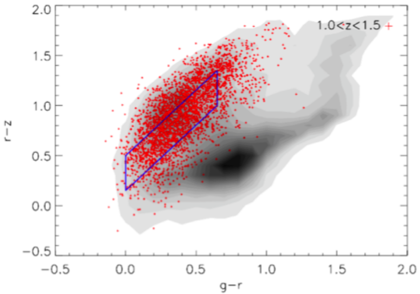
Outline

Target Selection

- Galaxies principally targeted from existing/on-going imaging surveys; JDEM imaging not required
  - SDSS
  - PanSTARRS-1 (in commissioning)
  - Palomar Transient Factory (PTF, in operation)
- Galaxies selected using color; well-established method
- Does **not** require photo-zs
- See additional note on target selection

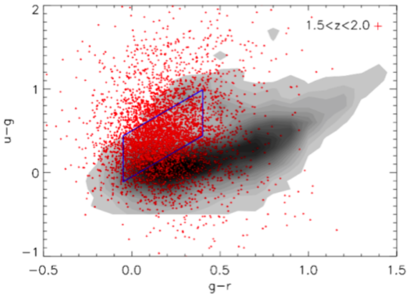
Selecting ELGs – O[II] emitters

z<1.6 sample
grz-selected



PTF *g*+*r* bands
+ PanSTARRS-1 *z*-band

1.5<z<2 sample
ugr-selected

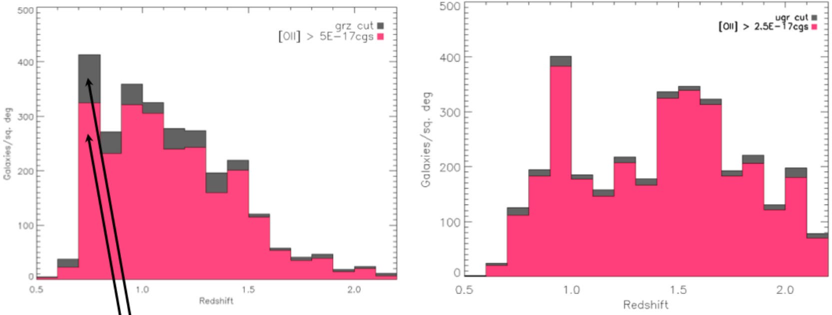


PTF *g*+*r* bands
+ CFHT *u*-band (proposed)

Selecting ELGs

z<1.6 sample
grz-selected

1.5<z<2 sample
ugr-selected

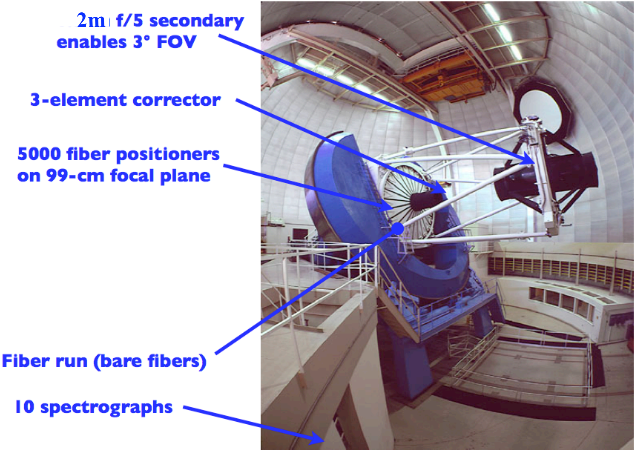


Galaxies satisfying color-mag cuts

... and detectable [O II] emission

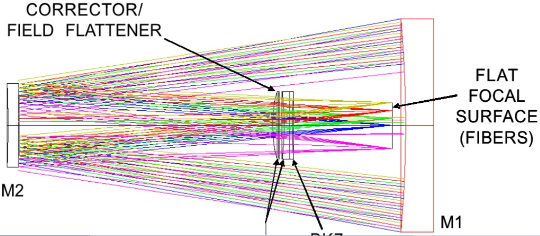
The Telescope

4-m (Mayall) at Kitt Peak, Arizona



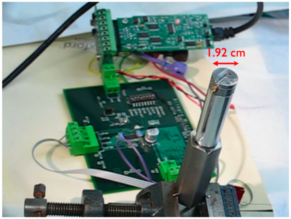
The Telescope

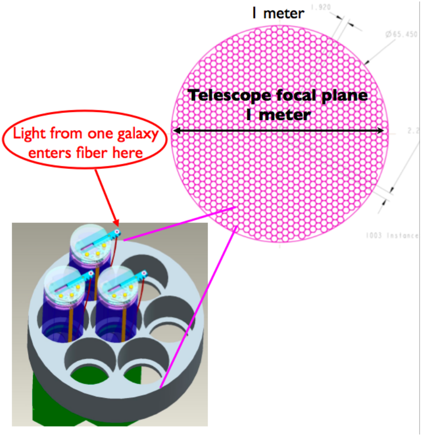
- Mayall is slow RC, making correction to 3° field possible
- All magnification is in 2m secondary
  - *2m blank already exists at LBNL*
- Corrector lenses add no power
  - Simple fused silica
  - No CaF
- Small aspheric deviations; low-risk
- Manufacturing feasibility verified by U.Arizona College of Optical Sciences



Fiber Positioners

- LBNL prototype
- Each positioner **individually** actuated
- Fibers extend into adjacent cells, no dead space
- Reconfiguration time $<$ 1 min.
- New 1.1cm design

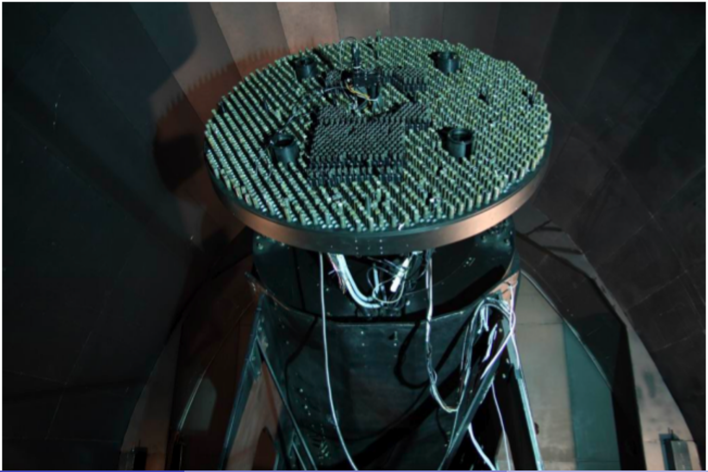




Fiber Positioners

Collaboration with USTC in Hefei, China

Experience building LAMOST fiber positioners
Similar design (2 rotation axes with Micromo motors) at 2.54 cm center-to-center spacing

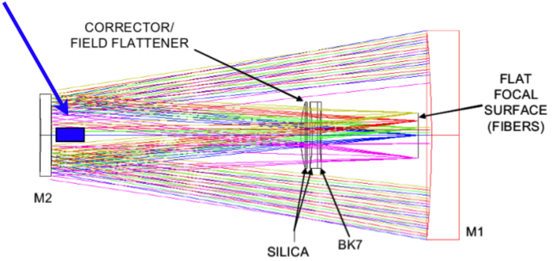


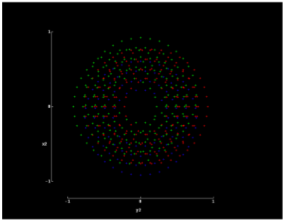
Fiber View Camera

Image fibers from near M2

Calibrates positions of all the fiber "zero positions"

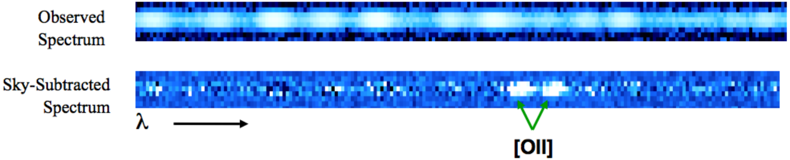
Back-light fibers within the spectrograph
9k x 9k camera sits in optically-unused spot near M2





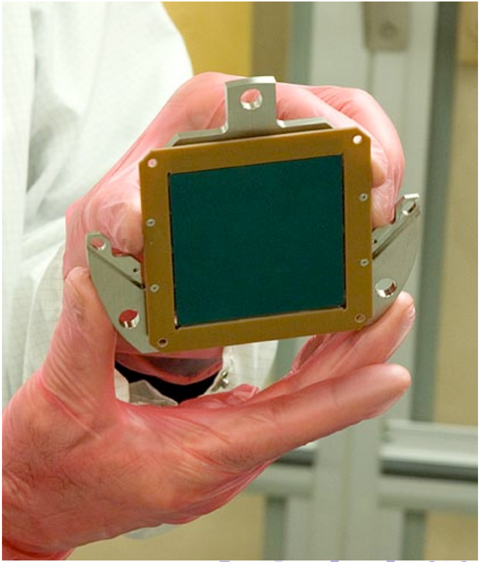
Inner 40 cm of M2 unused optically

The Spectrographs

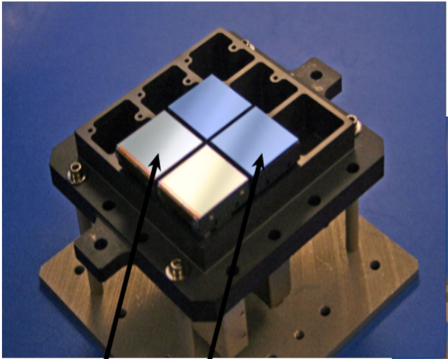


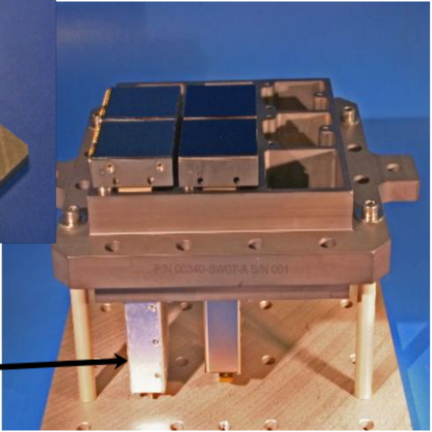
- R = 5000 spectrograph
  - Work between the sky lines
  - Resolve the O[II] doublet
- LBL/e2v CCDs to $z = 1.6$, HgCdTe to $z = 2.0$
- Detectors have BOSS/SNAP heritage

The Spectrographs - BOSS Heritage



The Spectrographs - SNAP Heritage





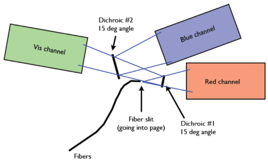
HgCdTe's CCD's

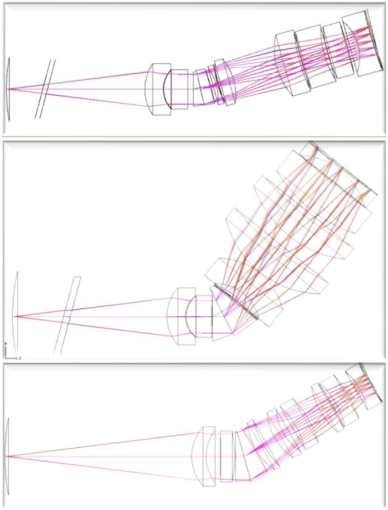
Electronics Module

Cryogenic readout modules
ADC and Clock Generation
(inside dewar)

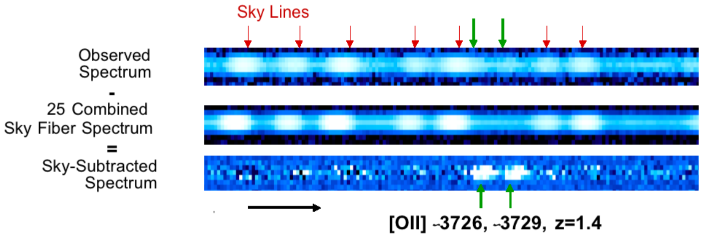
The Spectrographs

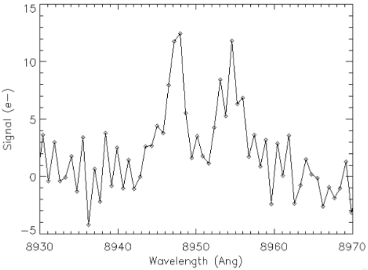
- Three spectrographs
  - Wide wavelength coverage, improved redshift ID
  - UV : 340-580nm
  - Visible : 540-970nm
  - NIR : 940-1130nm
- Feasibility studies completed





Spectrum Simulation





- The majority of BigBOSS redshifts will come from measuring the [OII] forbidden transition (rest-frame 3727Å), much like DEEP2 and **MUCH** different from JDEM
- Sky lines are well resolved and subtracted from object spectra assuming noise from 25 sky fiber spectra
- After sky subtraction, [OII] doublet with single line MLDF = 2.5E-17 cgs flux is clearly visible above the noise (extracted S/N~8)

Data Reduction/Distribution

- Data reduction from fiber spectrographs well understood
- All data and derived products will become public
- Rich data set for community
- SDSS/BOSS heritage

Preliminary Project Organization

LBNL – Lead DoE Institution

- Construction Management - LBNL
- Spectrograph Optics - France
- Spectrograph Detectors & Electronics - LBNL
- Spectrograph Dewars - Yale & Others
- Fiber Positioner - China
- Fiber Control and FiberView Camera - Yale
- Focal Plane Mechanics & Guiding - LBNL
- Optics Assembly - NOAO, LBNL, Arizona
- Instrument Operations - Various
- Telescope Operations - NOAO
- Data Management - NYU
- Data Reduction - Utah

Technical Status

- Spectrograph
  - Spectrograph optics are based upon BOSS, optical concepts exist for all three arms
  - Blue arm detectors are existing e2V devices
  - Red arm detectors are existing LBNL devices
  - NIR arm detectors are existing Teledyne devices
- Telescope Optics
  - Optical design concept exists for 3 degree FOV with Zemax solutions and manufacturer quote
- Fiber Positioner
  - LBNL fiber positioner proof-of-principle exists
  - LAMOST 4000 fiber spectrograph
- Data Management and Reduction
  - Plan has BOSS heritage and BOSS team in place

Further R&D

- SNAP and BOSS detectors, spectrographs, software, & electronics, have provided a major technical foundation.
- Feasibility demonstrated, next step is a full conceptual design.

- NIR device performance (noise) would benefit from continued R&D
- Project has a descope plan replacing Teledyne devices with LBNL CCDs
  - would decrease ELG redshift range from z<2 to z<1.75
- Trade studies through conceptual design phase
  - Redshift range
  - Number of fibers
  - Telescope FOV
  - Detector performance

Risks

- Programmatic
  - Decadal Survey in US
  - France roadmap, INSU, IN2P3 funding
  - China funding through Ministry of Science and Technology
  - University cost offsets
- Facilities
  - Adequate access to 4m
- Scientific
  - For $z > 1.6$, u-band survey, part of France contribution
- Technical
  - For $z > 1.7$, NIR operations has technical risk (detectors, cooling, bkgd.)
- Cost
  - Insufficient nights/yr will increase operating costs
  - NIR operation has cost risks
  - Complexities of international partnerships

Total Costs (FY09, M$)

- Construction costs principally funded by DoE.
- Key technologies through international partners.
- Operating costs funded by a combination of NSF, DoE, University partners
- Modeled on SDSS-I/II/III funding plan

BigBOSS Cost Breakdown

WBS	Description	Cost by WBS	Offsets: Major in kind contributions		Offsets: University Contributions
1.0	Project Management & System Engineering	5.1			5.0
2.0	Spectrographs and Instrument Electronics	30.9	10.6	France	
3.0	Fiber System with Positioners	5.4	4.8	China	
4.0	Optics	8.4			
5.0	Contingency	15.0			
6.1	Instrument Operations (6 years)	10.5			5.0
6.2	Data Operations (7.5 years)	9.6			
	Total Project Cost -- Construction + Ops:	**84.9**			
	Total Contributions:	25.4			
	Total DOE Cost -- Construction only:	**44.4**			
	Total DOE Cost -- Ops. only:	**15.1**			

Budget breakdown

WBS Level 2 3 4	Description	Total	Basis of Estimate
1	**Construction Project Management and System Engineering**	**5.1**	
1 1	Project Management (includes Administrative Support)	1.9	DES and Daya Bay, LBNL Labor Rates
1 2	Systems Engineering and Quality Assurance	3.2	DES and Daya Bay, LBNL Labor Rates

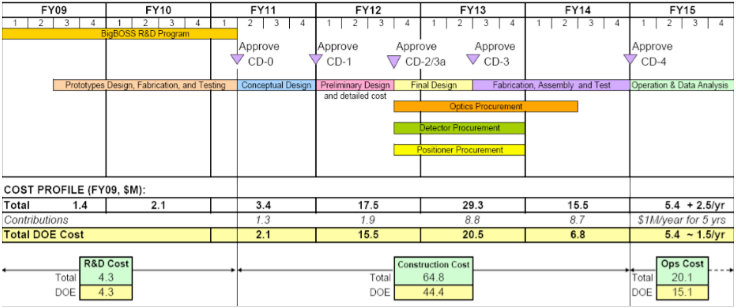
2 3 4	Description	Total	Basis of Estimate
2	**Spectrographs and Instrument Control Electronics**	**30.9**	
2 1	Spectrograph Optics and Structure (x10)	10.7	
2 1 1	Management	0.68	
2 1 2	Systems Engineering	1.67	
2 1 3	Structure	0.68	
2 1 4	Slithead	0.14	
2 1 5	Collimator Assembly	0.56	WFMOS Spectrograph Proposal and BOSS actuals
2 1 6	Hartmann Doors and Shutter	0.12	
2 1 7	Central Optics	1.62	
2 1 8	Blue Camera	1.46	
2 1 9	Visible Camera	1.29	
2 1 A	Red Camera	1.29	
2 1 B	Controller	0.47	
2 1 C	Integration and Test	0.72	
2 3	Detector Assy 1	4.00	
2 3 1	Dewar and Vacuum System	2.30	Engineering Estimate, BOSS actual
2 3 2	Detector [4kx4kx15u e2v]x10	1.30	Vendor Quote from e2v
2 3 3	Front End Electronics [CRIC 5.0 - CLIC 5.0]	0.40	Engineering Estimate, SNAP Prototype Build
2 4	Detector Assy 2	2.60	
2 4 1	Dewar and Vacuum System	1.00	Engineering Estimate
2 4 2	Detector [4kx4kx15u LBNL]x10	1.20	Vendor Quote from MSL
2 4 3	Front End Electronics [JDEM CCD F/E module]	0.40	Engineering Estimate, SNAP Prototype Build
2 5	Detector Assemblies 3	11.80	
2 5 1	Dewar and Vacuum System	0.50	Engineering Estimate
2 5 2	Detectors [2 each 2kx2kx18u Teledyne +2 each 4kx4kx15u LBNL]x10	10.80	Vendor Quotes from Teledyne and MSL
2 5 3	Front End Electronics [JDEM SIDECAR module]	0.50	Vendor Quote from Teledyne
2 6	Digital Electronics System	1.80	
2 6 1	Positioner Control Elect. with Camera Interface	0.10	Engineering Estimate
2 6 2	Science Data Processing and Control Electronics	0.20	Engineering Estimate, SNAP Prototype Build
2 6 3	Software	1.50	Engineering Estimate, BOSS actual

2 3 4	Description	Total	Basis of Estimate
3	**Fiber System with Positioners**	**5.4**	
3 1	Fiber Assembly [block w/ 500 150u fibers]x10	1.2	Vendor quote (catalog item), BOSS actual
3 2	Positioner Assemblies	3.8	Engineering Estimate, Prototype Build Invoices
3 3	Fiber Support Tray System	0.4	Engineering Estimate
4	**Optic**	**8.4**	
4 1	Upper Mechanical Structure	0.9	Engineering Estimate from KPNO
4 2	Secondary Mirror	3.5	Quote from U. Arizona Optical Sci.
4 3	Fiber Position Camera Assembly	0.1	Fairchild Off-the-Shelf Product
4 4	Lower Mechanical Structure	0.9	Engineering Estimate from KPNO
4 5	Cassegrain Cell Assembly	0.8	Engineering Estimate from KPNO
4 6	ADC Assembly	0.8	Engineering Estimate from KPNO
4 7	Focal Plane Assembly	1.4	Engineering Estimate
4 7 1	Mounting Plate and Structure		Engineering Estimate
4 7 2	Guider Modules		Semi-custom designs & built around a standard CCD
4 7 3	Auto Focus Modules		
5	**Contingency**	**15.0**	Based on 30% on all construction costs. Contingency on Ops included in 7.0

2 3 4	Description	Total	Basis of Estimate
6	**Pipeline and Operations**	**20.1**	
6 1	Instrument Operations	10.5	KPNO estimates
6 1 1	Spectrograph Operations (including dewars, detectors)	3.0	
6 1 2	Associated Computers	1.5	
6 1 3	Non-Spectrograph Hardware	1.5	
6 1 4	Telescope Operations	3.0	NSF/NOAO
6 1 5	Management/Admin Support	1.5	
6 2	Data Management Budget	4.5	SDSS running costs
6 2 1	Science Archive Servers and Mirror	0.8	
6 2 2	Maintenance and Facility Support	1.4	
6 2 3	Data Archivist and Coordinator	0.8	
6 2 4	Catalog Archive Administrators and Licensing	0.6	
6 2 5	Software Development	0.9	
6 3	Data Reduction	5.1	Estimate, based on BOSS projected
6 3 1	Project Management	0.6	
6 3 2	Data Reduction and Packaging	1.0	
6 3 3	Code Development	2.2	
6 3 4	Target Selection	0.8	
6 3 5	Computing Hardware, Support and Licensing	0.5	

Schedule

- First light in 2015; aggressive schedule
- Ideally timed, phased to begin as BOSS/DES end, LSST begins
- Assumes CD-0 Q1 FY11



Collaboration

- BigBOSS a collaboration between DoE, NSF, US universities, Foreign participation groups
- Modeled after SDSS-I/II/III; DES
- Current steering group consists of members from LBNL, NOAO, Yale, Utah, Marseille, USTC (China).
  - BigBOSS on France P0 roadmap
- Collaboration very active, and growing

Steering Committee

Contacts:**David Schlegel (LBNL)**, **Arjun Dey (NOAO)**

- **Charlie Baltay**, Yale Univ.
- **Arjun Dey**, National Optical Astronomy Observatory
- **Anne Ealet**, Centre de Physique de Physique des Particules de Marseille
- **Yipeng Jing**, Shanghai Astronomical Observatory
- **David Kieda**, University of Utah
- **Jean-Paul Kneib**, Laboratoire d'Astrophysique de Marseille
- **Michael Levi**, Lawrence Berkeley National Laboratory
- **David Schlegel**, Lawrence Berkeley National Laboratory
- **Chao Zhai**, University of Science and Technology of China

Outline

Inter-Agency Issues : DoE+NSF

- BigBOSS will use the Mayall 4-m telescope at Kitt Peak, AZ, operated by NOAO/AURA on behalf of NSF => requires DOE+NSF partnership
- Telescope time on NOAO facilities is traditionally obtained through open competition
- Telescope time can be obtained for both small PI projects (few nights) and large surveys (large blocks of nights, multi-year)
- Dark Energy Survey sets a precedent for a DOE-NSF joint venture
    - Awarded 525 nights over 5 yrs.
- BigBOSS can follow a similar path

The Astronomy Context

- BigBOSS presented to Decadal Survey and NOAO Users Group
  - Response has been positive!
- NOAO developed plan for $<$6m telescopes through ReSTAR committee (Renewing Small Telescopes for Astronomical Research)
- This committee's recommendations call for the specialization of the 2-4 meter class telescopes: *Specialization will provide a more limited set of observing capabilities on each telescope but should preserve a breadth of capability across the ReSTAR System.*
  - BigBOSS instrument = most ambitious low to mid-res spectrograph
  - BigBOSS consistent with ReSTAR recommendation

The Astronomy Context

- There are 7 4m class facilities in the US OIR system - Palomar 5m, SOAR 4.2m, KPNO 4m, CTIO 4m, WIYN 3.5m, ARC 3.5m, and Lowell 4.2m (in 2 yrs)
- KPNO and CTIO can be converted to 3 degree field (with identical optical elements)
- BigBOSS can be realized with **1/7** US 4m time
- ReSTAR committee also endorsed paying for displacement time on the US OIR non-federal 4m class facilities

Engaging the community

- Mayall is an open-use facility - must not disenfranchise US astro community
- Multiple opportunities to engage community
  - Collaboration on key dark energy projects
  - Parallel non-DE key projects
  - Fibers on survey nights (allocated through TAC process)
  - Unique instrument for US community
  - Public archive
- SDSS/BOSS/DES have successfully done this!

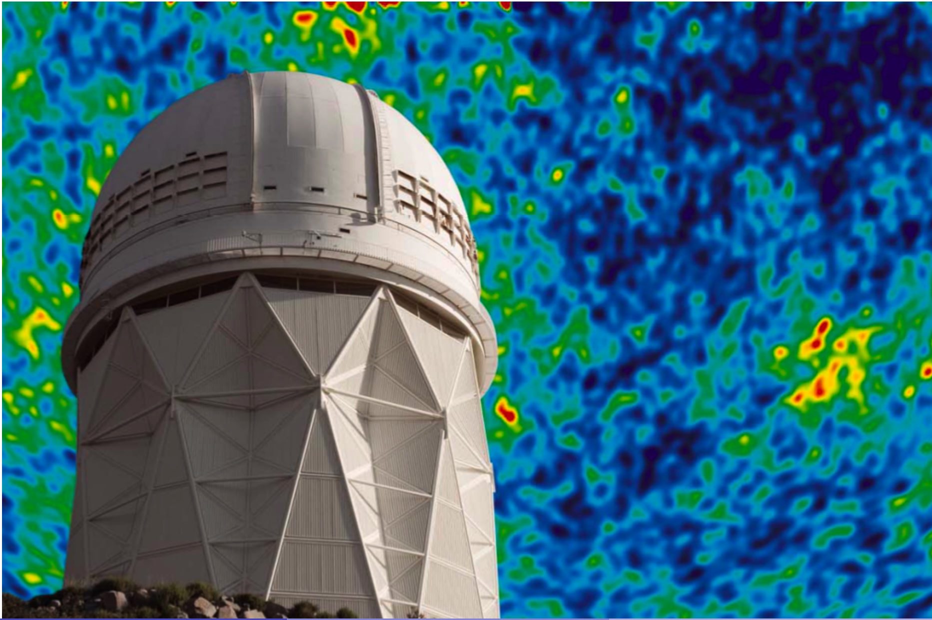
Conclusions

- BigBOSS - a Stage IV BAO experiment
- Natural progression from existing Stage III experiments
- Belongs on PASAG dark energy roadmap
- Complementary to planned Stage IV SN/WL experiments
- Unique instrument for US community

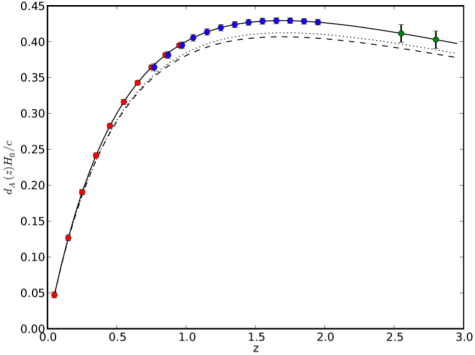
How PASAG can help :

- Endorse agencies support for a new instrument
- Endorse significant commitment (6+4 years) of a national facility

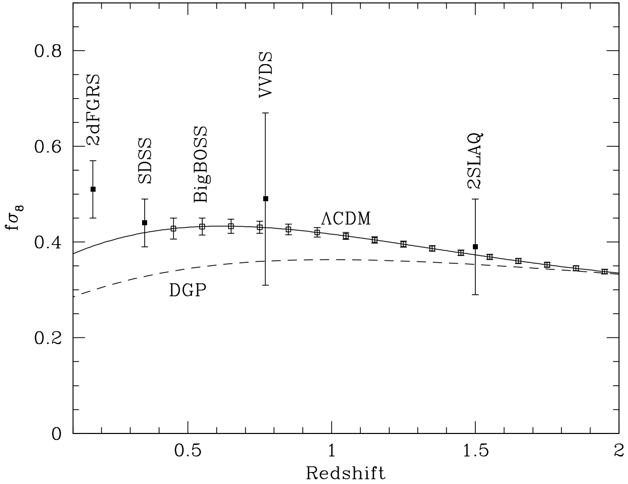
Strong support from PASAG vital to this process



Baryon Oscillations with BigBOSS



Growth

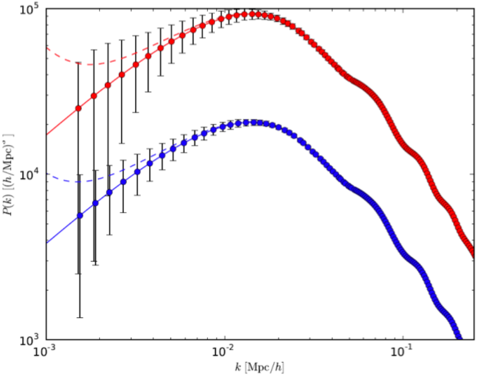


FoM **doubles** when redshift-space distortions are included.

Primordial non-gaussianities

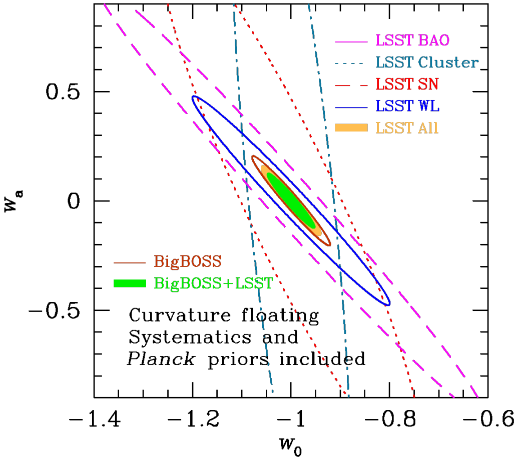
Tests of early Universe theories

- Scale dependent bias on large scales!
- Volume matters!
- $f_{NL} = 1$ interesting region
- Dashed line is $f_{NL} = 5$
- Compare multiple samples (suppress sample variance)



Complementarity

- Spectroscopic coverage for next-generation imaging surveys (PanSTARRS, DES, LSST)
- Photo-z calibration for weak lensing surveys
- Cross-correlation between 2D and 3D data
- Enhanced dark energy constraints



Hu Zhan, priv. comm.

DES Timeline

- Dark Energy Survey sets a precedent for a DOE-NSF joint venture:
  - Project is allocated 525 nights over 5 years for core science (1/3 telescope time)
  - Project was created as the result of an AO by NOAO for a wide-field instrument for the Blanco 4m telescope at CTIO in exchange for telescope time + some engineering resources
  - NSF contribution is in observing nights + upgrades to the Blanco telescope + operations support + PI funding for software pipeline development.
  - Announcement of Opportunity for Blanco Instrumentation Partnership - issued late 2003, letters of intent due in March 2004
  - DeCam end commissioning - Sep 2011